SINGLE *VS.* DOUBLE (ABUTTED) CONSONANTS ACROSS SPEECH RATE X-RAY AND ACOUSTIC DATA FOR FRENCH

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ABSTRACT

The aim of this investigation is to analyze, for French, the behaviour of single as opposed to double (abutted) consonants, from X-ray and acoustic data, for two speakers (one female and one male) with increase of speech rate. If configurational constraints have been proposed for articulatory modelling of vowels [1]; [2]; [3], those related to consonant production are lacking in the literature.

INTRODUCTION

X-ray data for consonant productions [4] is rare compared with those available for vowels in the literature. So also is work on the influence of speech rate on vocal tract configurations. The present investigation attemps, hopefully, to contribute, albeit modestly, to reducing this scarcity and also shed some light on articulatory-acoustic consonantal constraints.

METHOD

The corpus consisted of 58 sentences (of 4 to 6 syllables) that embedded the target words. These words were chosen to vary consonantal length /l, p, t, k, b, d, g/ *vs.* /ll, pp, tt, kk, bb, dd, gg/. The present investigation focussed on the following sentences:

Il a pas mal	*vs.*	Il zappe pas mal
/apa *vs.* appa/		
Les attabler	*vs.*	La chatte tachetée
/ata *vs.* atta/		
Très acariâtre	*vs.*	Trois sacs carrés
/aka *vs.* akka/		
Des abat-jour	*vs.*	Crabes bagarreurs
/aba *vs.* abba/		
Il l'a daté	*vs.*	Pas de date précise
/ada *vs.* adda/		
Crabes bagarreurs	*vs.*	Blagues garanties
/aga *vs.* agga/		

Note that all pairs of sentences had the same number of syllables. The data reported here is thus based on 14 out of the 58 sentences, produced by two speakers (S1 and S2) at a normal (conversational) speaking rate and at a self-selected fast rate. Thus there were 56 conditions in all: 2 speakers X 7 consonant types X 2 speech rates X two durational contrasts.

Recordings and measurements

X-ray films, together with a simultaneous audio recording of the speakers' productions were obtained.

With the help of a grid [5], measurement parameters for vocal tract configurations were determined related to lip-lip and tongue-palate (apex, body) contact-extents (mm); jaw opening (mm) and constriction width (mm), related to the preceding vowel were also measured. Temporal events were detected on the audio signal and specific timing relations between these events allowed determining, in the VC domain, acoustic durations (ms) that correspond to articulatory opening and closing gestures. Speech rate was varied as a perturbing factor of measures obtained from the different linguistic categories, thus allowing to test the resistivity of these patterns observed on both the geometric vocal tract and the acoustic timing levels.

RESULTS AND DISCUSSION

Results presented here are based on raw data and rarely on statistics as it was not possible to acquire data sufficient enough — due to experimental conditions (exposure to X-rays) — to carry out detailed statistic analyses. However, general *tendencies* will be distinguished from *systematic* observations, where the latter show

clear-cut differences across linguistic categories, rate conditions and speakers.

Measurements obtained from mid sagittal profiles, at normal speech rate, show that contact-extents (maximum value for contact) for lip-to-lip and tongue-to-palate (apex and body) productions are longer for double (abutted) consonants than for their single counterparts. This remark is valid, in an intraspeaker pairwise comparison, for all linguistic categories examined, *i.e.* bilabials, apicals and velars, and for both speakers. This difference in contact-extent is shown on Figure 1. of midsagittal tracings for /aka *vs.* akka/ and /ada *vs.* adda/. Table 1 (below) illustrates this fact.

Table 1. Contact-extents (mm) for single vs. double (abutted) consonants at a normal speech rate for S1 and S2.

Single consonants			Double consonants		
vcv	S1	S2	vccv	S1	S2
apa	8	10	appa	11	12
ata	3	8	atta	7	10
aka	7	10	akka	17	14
aba	8	9	abba	9	10
ada	6	3	adda	7	7
aga	9	10	agga	12	12

Although differences, in rare instances, may seem too minimal to be significant (1 mm), it should be noted that this obstruent strategy is always systematic (across several images) and in the same direction. Moreover, the global tendency for abutted consonants to have a longer contact-extent than their shorter counterparts is maintained in fast speech rate, thus showing the relevance of this parameter in differentiating the two categories, *i.e.* even when the linguistic system has been perturbed by speech rate increase. Table 2 (below) confirms this claim.

Table 2. Contact-extents (mm) for single vs. double (abutted) consonants at a fast speech rate for S1 and S2.

Single consonants			Double consonants		
vcv	S1	S2	vccv	S1	S2
apa	9	8	appa	9	10
ata	3	9	atta	9	14
aka	6	9	akka	22	27
aba	8	6	abba	10	9
ada	9	4	adda	14	10
aga	10	12	agga	13	13

Such differences are more or less maintained in fast speech. Increasing speech rate, leads to an increase in contact-extent for single and double consonants (compare values in Tables 1 & 2). This is especially true for the lingual consonants. The difference in behaviour between lingual consonants and bilabials as to their contact-extents has been reported elsewhere [6] for these two speakers, in an entire corpus of 58 sentences embedding varied consonants and vowels, at the two speech rates; the tendency is for contact-extent to increase with speech rate increase for lingual consonants and to remain relatively stable for bilabials. It can be hypothesized that this parameter does not only correspond to the obstruent phase of the plosive; it may also reflect, in cases where the linguistic system is perturbed, an "articulatory overshoot" phenomenon in terms of speed of lingual muscular tissue impact on the hard palate. If contact-extent does, however, reflect the obstruent phase of the consonant, then there should be some relationship between this articultory parameter and closure duration on the acoustic level (cf. *infra*). The other two articulatory parameters, jaw opening and constriction width, did not show any systematic coarticulatory behaviour. These parameters, exploited in terms of area measurements, should certainly give pertinent information in distinguishing single from double abutted consonants.

On the acoustic level, in both speech rates, mean values for closure duration for all double consonants are systematically longer than that of their single counterparts (210 ms *vs.* 90 ms respectively in normal rate; 120 ms *vs.* 70 ms respectively in fast rate). These are all clear-cut differences, indicating that closure duration is a more robust measurement than contact-extent in distinguishing single from double consonants. With speech rate increase, both single and double consonants reduce their closure duration, but it is the double consonants that undergo a higher reduction (around 90 ms) than the singles (around 20 ms). It has been reported that under speech rate increase, long elements (vocalic or consonantal) tend to resist less to syllable compression than the already short elements even when the short element is a vowel [7]. This has been explained in terms of linguistic constraints for identity preservation, as further compression of short elements would affect their identification [8].

Is there an explicit relationship between contact-extent and closure duration? Figure 2 (left) shows that there is no strict intra-class or inter-class correlation between the two parameters. However, when all conditions are collapsed, and at a normal speech rate, double consonants with markedly longer closure durations, tend to have longer contact-extents than single consonants. This tendency is maintained in fast speech (Figure 2, right).

As concerns vowel duration of V1, mean values obtained are comparable for both classes in normal speech rate (110 ms); when speech rate is increased the vowel for the double class is reduced by 50 ms, whilst that for the singles is reduced by only 25 ms. It seems, indeed, that the longer categories are less resitant to compression provoked by speech rate.

CONCLUSION

Data for consonantal single and double (abutted) consonants have been analyzed and a relevant measure has been unveiled: articulator contact-extent. This is a robust parameter since it is also valid in distinguishing the two linguistic classes, even when speech rate is increased. Moreover, the relationship between contact-extent and closure duration has been demonstrated. Such regularities are useful in evaluating the non linear relationship between geometric parameters and the acoustic output. Thus, if contact-extent is related to closure duration, it also carries information on articulator speed and resulting impact; these factors, however, call for a more thorough analysis. Although articulatory parameters related to the preceding vowel did not show any consistent behaviour, converting the midsagittal measures we obtained to area functions should furnish relevant information for modelling.

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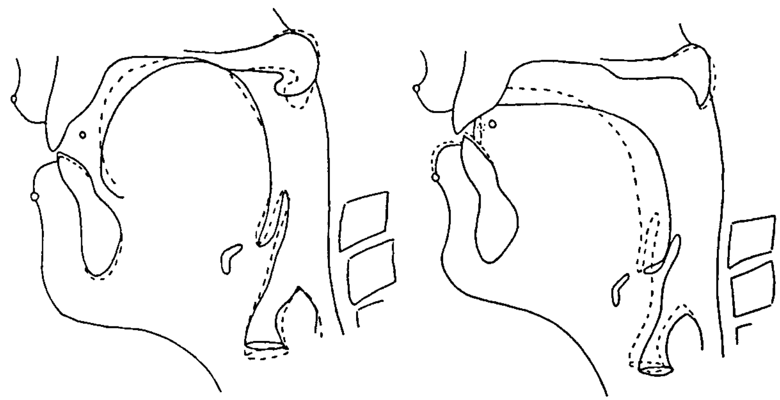

Figure 1. Vocal tract sagittal profiles for /aka/ (bold lines) vs. /akka/ (dotted lines) in normal speech rate (left) and for /ada/ (bold lines) vs. /adda/ (dotted lines) in normal speech rate (right), for Speaker 1.

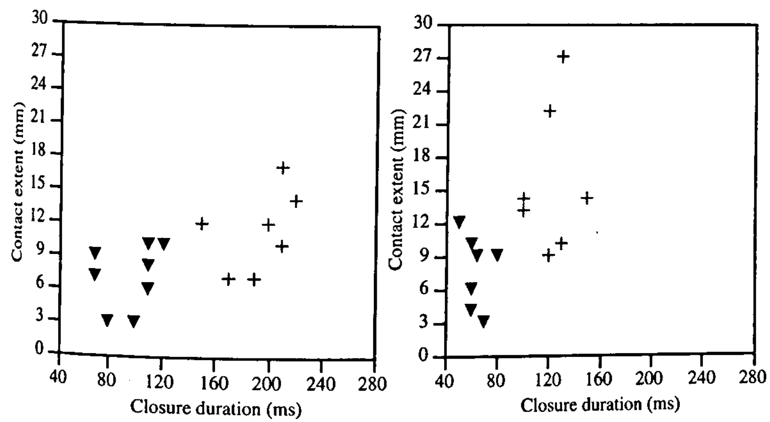

Figure 2. Scattergrams of tongue-palate (apicals and velars) contact-extents (mm) as a function of closure duration (ms) for single (▼) vs. double (+) abutted consonants in normal (left) and fast (right) speech rates. Speakers 1 and 2.